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Full-Gap Tracking System for Parallel-Plate Electrostatic Microactuatores

E.E. Moreira[a]*, F.S. Alves[a], R.A. Dias[b], J. Cabral[a], J. Gaspar[b] and L.A. Rocha[a,b]

[a]*ALGORITMI CENTER, Universidade do Minho, Campus de Azurém, Guimarães, Portugal*
[b]*INL, International Iberian Nanotechnology Laboratory, Braga, Portugal*

Abstract

An approach aiming bidirectional full-gap tracking of parallel-plate electrostatic microactuators is presented here. The approach is based on an On-Off control law, manipulating the structure location by actuating or releasing the device if the actual location is greater or smaller than the reference desired position. The existing ripple is due to delays on the readout circuit and control circuitry. In order to minimize delays on the control part, a high sampling frequency, 5MHz, is used. Experimental results show the tracking of signals up to 100Hz and an extended travel range up to 88.9% of the full available gap (limited by the existing mechanical stoppers of the devices).

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Keywords: Actuators, Control System, FPGA, MEMS, Tracking

1. Introduction

Parallel-plate electrostatic microactuators are widely employed in MEMS applications, yet they have a limited displacement of 1/3 of the gap available, due to the pull-in phenomenon. Several ways to increase the displacement have been proposed in the literature [1]–[5], with control laws adapted to MEMS requirements [2]–[5], but still with limited frequency and extended-gap response.

* Corresponding author. Tel.: +351 253 510 180; fax: +351 253 510 189.
E-mail address: a58787@alunos.uminho.pt

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A bi-directional full-gap tracking system based on On-Off control [1],[3] is presented here. The microdevices used have parallel-plate electrodes that are actuated or released in order to place the structure in the desired position. In addition, the device displacement is bi-directionally controlled [5], enabling the tracking of negative and positive references.

2. Tracking system design

As represented on the block diagram depicted in Fig.1, the central part of the system is the electrostatically actuated parallel-plate structure. A digital to analog converter (DAC) and an analog to digital converter (ADC) are responsible for actuating and reading the charge amplifier-based readout circuit respectively [6]. In order to guarantee control efficiency and a digital implementation, the control was implemented on a field programmable gate array (FPGA), increasing its reliability. The FPGA also has modules for the carrier generator (charge amplifier) and the communication protocol (UART), as well as the control of the actuation and acquisition systems.

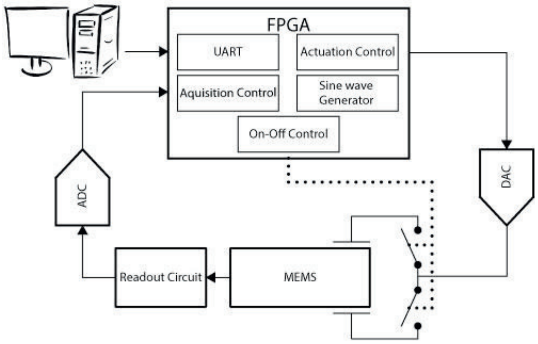

Fig 1. Block diagram of the implemented system.

The working principle of the implemented On-Off control law is based on the comparison of a reference chosen by the user with the readout output value: if the reference is positive and larger than the actual position, the device is actuated with a voltage higher than the pull-in voltage; otherwise it is grounded by means of a digital switch. The same law is repeated to negative reference values, but a different switch is used to actuate on the other side of the microstructure, allowing bi-directional movements.

3. Results

The system was tested with two different structures (structure #1, slightly underdamped, Q = 1.75, and structure #2, overdamped, Q = 0.33) fabricated using an in-house SOI process (Fig. 2).

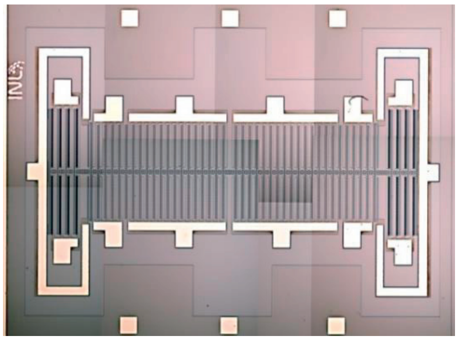

Fig 2: Microscope picture of the slightly underdamped microdevice (structure #1, Q = 1.75).

Both structures have stoppers limiting the displacement at 2μm. Given the 2.25μm initial gap, this corresponds to a displacement range extension of 267% or stable position up to 88.9% of the gap (Fig. 3a).

The tracking of sinusoidal displacement profiles was successfully tested, allowing signal tracking up to, at least, 100Hz of frequency (Fig. 3b). The simulated results, using a Simulink model, presented on Fig.3b are in agreement with the experimental ones, validating the implemented tracking system. The measured ripple, due to delays on the readout electronics, is at the same level as the simulated one.

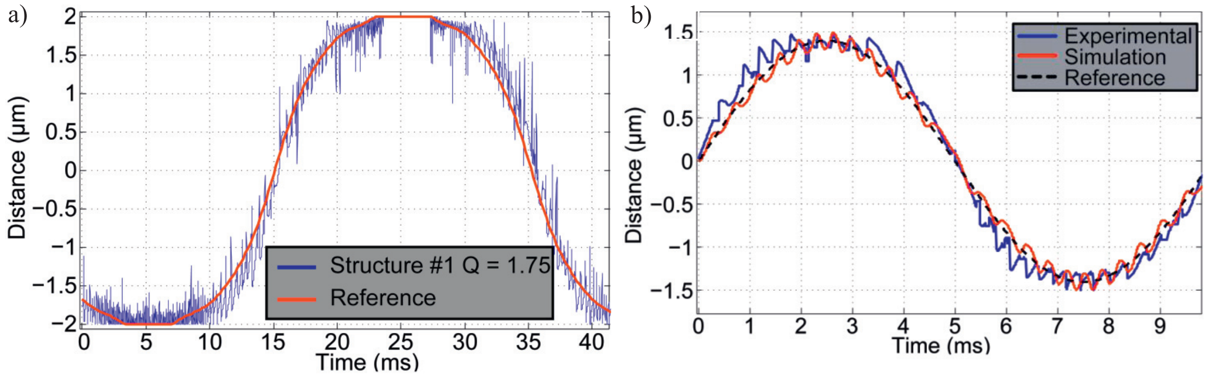

Fig 3: a) Experimental tracking of a 100Hz sine wave reference. b) Experimental results of a full-gap 25Hz sine wave tracked using a 5.7V actuation voltage (displacements are limited to 2 μm).

The system was successfully tested while tracking different wave forms, as depicted in Fig.4a. The two fabricated devices were tested, comparing the measured ripple while tracking a 5Hz sine wave. As shown in Fig. 4b, structure #2 presents smaller ripple due to its lower quality factor, when comparing to structure #1.

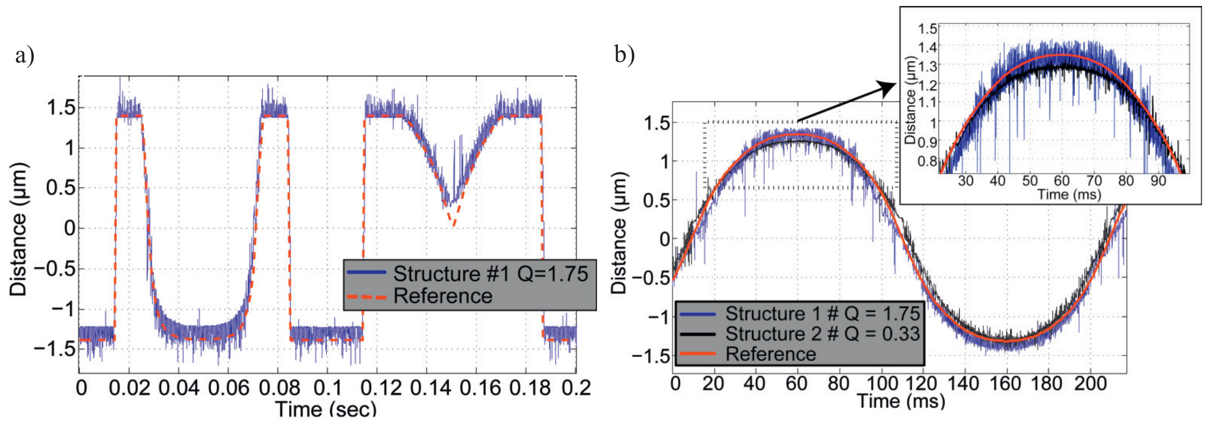

Fig 4: a) Experimental track of a wave containing the acronym from University of Minho (UM) at 5Hz; b) Experimental results of structures #1 and #2 tracking a 5Hz sine wave.

The existing ripple is mainly due to the delays on the control path, and therefore, the higher the sampling and switching frequency, the smaller the ripple. Also, the charge amplifier used in the readout circuit is affected by the switching on the actuation voltage, resulting in an extra noise signal added to the output. Thus, the experimental results appear to have a higher ripple than it really exists due to switching induced electronic noise on the readout voltage.

At high tracking frequencies the microstructure response is slower than the reference and a metastability region appears [7] as illustrated in Fig.5. Although not critic, this problem can be solved by increasing the ON voltage.

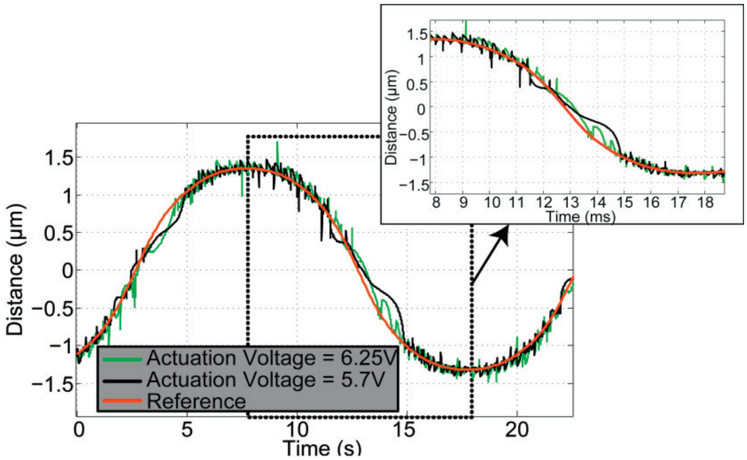

Fig 5: Experimental measurements of structure #1 for a 50Hz tracking signal with two different actuation voltages. Metastability is visible for the lower actuation voltage.

The ON actuation voltage (always higher than the pull-in voltage) can be adapted to the tracking frequency and thus improving the control. Increasing the actuation voltage results in a higher electrostatic force which reduces the travel time of the structure. This enables the tracking of higher frequency reference signals.

4. Conclusion and Future Work

An On-Off based full-gap tracking system for parallel-plate electrostatic microactuators was proposed here. The control system was implemented on a FPGA increasing its performance and reliability.

The used devices have two sets of actuation electrodes enabling bi-directional tracking. The system was tested for different wave forms at several frequencies and stable displacements up 88.9% of the full-gap, limited by physical stoppers on the device, were achieved. The experimental results prove the efficiency of the proposed tracking system, with a displacement range extension of 267%.

Acknowledgements

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